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DIASTROPHISM AS THE ULTIMATE BASIS OF CORRELATION

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There are many and diverse views relative to the nature and the causes of diastrophic movements. To keep as largely as may be on common ground, most of these divergencies of view may be set aside as immaterial to our present purpose. We may all agree that the fundamental factors of the case are a lithosphere with a deformable surface, a liquid, covering part of this surface and determining erosion and sedimentation, and a gaseous envelope. We may easily agree that the outer part of the lithosphere is solid and has a sufficient measure of rigidity to maintain the surface inequalities. I do not see that we need to agree as to the causes of deformation. In some sense, I do not see that we need even to agree as to just what the absolute movements were, i. e., I do not see that it is material for us here to know whether the deformative movements were shrinkages, or expansions, or lateral shifts, provided we agree as to the general nature of their effects on the agencies at work on the surface of the lithosphere. We do not need to entertain the same conception of the nature of the earth's interior, if we are at one as to the working conditions which have prevailed on its surface.

No doubt we can easily agree on the present great working factors: (1) abysmal basins occupying about two-thirds of the earth's surface, bordered by terrace faces rising at angles of 2° to 5° for say 12,000 feet to a quite definite terrace-angle about 100 fathoms below the sea-level; (2) continental platforms whose upper faces slope gently up from this angle to the coast-line and thence ascend into the various reliefs of the land. If we thus agree that the upper face of the continental platform is bounded by the edge of the continental shelf, and that this edge is equally the boundary of the abysmal basins, whether the waters overlap the edge or not, we may also agree that the edge of the oceanic waters, whether they agree with the edge of the abysmal basins or not, form the chief line of demarkation between the great erosions and the great depositions the world over. It is not the only line of such demarkation, to be sure, for degradation gives place to aggradation at many other local horizons, but in this discussion let us agree to deal only with factors of the larger order and to neglect incidentals; let us deal with body deformation, rather than local or provincial warpings. We all recognize further that the sea-level is not only a dividing plane between two great divisions of physical agencies, but between two great biological divisions.

To this list of agreements, there are two other propositions which we cannot add quite so unhesitatingly, because we need to weigh them well, and if we cannot all agree respecting them, we must agree to differ, for they are fundamental to the further discussion. These relate to the effects of body deformation on the relations of land and sea.

If deformation were confined to the abysmal bottoms and were compensatory, no effect would be felt on the relations of land and sea. If deformation were confined wholly to the interior of the continents, it would be similarly ineffectual. Deformations so limited are, however, likely to be only provincial, and fall outside our discussion.

There remain two conceptions of general or body deformation between which choice must be made. In the one, the deformations are supposed to be indifferent to their predecessors, and to disregard the configurations produced by previous deformations. Their successive effects upon continental outlines and basin capacities are thus heterogeneous and the combined results irregular and uncertain. It is not clear to me how they can be made a very trustworthy basis of systematic correlation. The submergent phase of one continent or fraction of a continent may, in this case, be contemporaneous with the emergent phase of another continent or fraction of a continent, and the progress of events on one continent is as likely to be contrasted with those of another continent as to fall in with them co-ordinately.

According to the other view, deformations are inheritances, one of which follows another in due dynamical kinship. The succession is therefore homogeneous and the results co-ordinate. If, for example, the first depression of the abysmal basins was due to the superior specific gravity of the basin-bottoms, this specific gravity remained and participated in the next deformation. If the continental masses, at the outset of continental formation, were relatively low in specific gravity, this low specific gravity was handed down to later periods and helped to renew deformation of the same phases in the same regions. Under this view, ocean basins and continental elevations tended toward self-perpetuation. It is not assumed that this prevented shell crumplings, provincial warpings, or block movements of diverse phases within the continental or the abysmal areas, for these might obviously be necessary effects of the general deformative movements, or at least inevitable incidents connected with the dynamics lying back of them.

A choice between these two conceptions is imperative to this discussion, as they lie at the parting of the ways in the interpretation of the larger events of geologic history. I accept the second view with much confidence. It should be more fully qualified respecting the incidental accompaniments just mentioned, but time does not permit.

According to this view, each great diastrophic movement tended toward the rejuvenation of the continents and toward the firmer establishment of the great basins. The distinction between continent and basin must not, however, be interpreted on the superficial ground of the water-line, for the water-line merely shows that the basin is over-full, just full, or under-full, as the case may be. The average water-line undoubtedly helps to give a definite terrace border to the abysmal basin, but the water-line freely abandons this and often is far from coinciding with it.

The base-leveling processes have shown that they are able to lower the continents approximately to the sea-level in a fraction of geologic time. The continents would therefore have long since disappeared, if they had not been rejuvenated by renewed relative elevation or the withdrawal of the sea. I am able to find no evidence of lost continents. There are submerged margins, and matter has been carried continent-ward from denuded borders. There are some submerged dependencies and inter-continental connections. There are also some rather deeply submerged ridges that probably connected the present continents at remote stages in their history. In the earlier eras, when the differentiation of platforms and basins was less advanced, ridges which have since been submerged are perhaps recognizable. In the interpretation of the earlier periods, these should probably be restored as continental connections. In the earliest known ages, these may have been rather numerous and their combined area considerable, but these seem to me to be only qualifying features which, by the natural place in evolution which they fill, support, rather than weaken, the general conception of a systematic succession of deformations in which the offspring of each is the parent of the next, and in which both continents and ocean basins were progressively segregated and unified.

I trust that many of you will agree that, in general, the relatively upward movements of diastrophism have been located continuously in the continents, and the broad downward movements continuously in the ocean basins, and that, setting aside incidental features, the dominant effect of the successive diastrophic movements has been to restore the capacity of the ocean basins and to rejuvenate the continents. This conclusion seems to me to be strongly supported by the general course of geologic history, wherein sea-transgressions and sea-withdrawals have constituted master features. Perhaps our firmest ground for this conviction is found in the present relations of the continents and the sea basins. If heterogeneity had dominated continental action in the great Tertiary diastrophisms, the results should stand clearly forth today. Some continents should show recent general emergence, while others should show simultaneous general submergence. The dominant processes today should be those of depressional progress, on the one hand, and those of ascensional progress, on the other. As a matter of fact, all the continents are strikingly alike in their general physiographic attitude toward the sea. They are all surrounded by a border-belt, overflowed by the sea to the nearly uniform depth of 100 fathoms. These submerged tracts are all crossed by channels, implying a recent emergent state. None of the continents is covered widely by recent marine deposits, and yet all show some measure of these. Wide recent transgressions in one part do not stand in contrast with great elevations in another. Even beyond what theory might lead us to expect, when we duly recognize the warpings incidental to all adjustments, the recent relations of the continents to the seas conform to one type. The 10,000,000 square miles of continental margin, now submerged, is distributed around the borders of all the continents with a fair degree of equability. May we not, therefore, agree that in the world-wide phases of diastrophic movements, the basins have been additionally depressed and the continents repeatedly rejuvenated.

It is important that we should agree, or agree to disagree, on one further point. Have diastrophic movements been in progress constantly, or at intervals only, with quiescent periods between? Are they perpetual or periodic? The latter view prevails, I think, among American geologists. This view has acquired especial claims since base-leveling has come to play so large a part in our science, for it is clear that the doctrine of base-leveling is specifically inconsistent with the doctrine of perpetual deformation, for the very conditions prerequisite to the accomplishment of base-leveling involve a high degree of stability through a long period. The great base-levelings, and the great sea-transgressions, which I think are little more than alternative expressions for the same thing, have, as their fundamental assumption, a sufficient stability of the surface to permit base-leveling to accomplish its ends. Shall we not therefore agree that there has been periodicity in the world-warping deformations? Let this not be held with such exclusiveness that we fail to recognize duly the effects of the adjustment of minor stresses, at other times. These may be preliminary or after-effects of the larger movements, or they may be due to local stresses more or less independent of the general body-stresses. These quite certainly have been present, and have produced intercurrent departures from the strict tenor of the great systematic movements.

If there is need for additional argument on periodicity, it may be found in theoretical considerations, but these we have tried to avoid in the main. Whatever we may regard as the fundamental agencies that give rise to those stresses in the earth which are precedent to deformations, we may easily all agree that the earth opposes some resistance to deformation. There is certainly some rigidity in the body of the earth. According to the fundamental laws of rigidity, the deforming stresses must reach a certain magnitude before a movement can start. Now, if we recall that every such deformative movement, affecting a free surface, in its very nature, throws the resisting crust into an attitude of relative weakness, it follows that, with such progressive easing, the movement will go on until the stress is accommodated and a state of equilibrium essentially restored, after which another period of accumulation is prerequisite to another movement.

If we are agreed on the periodicity of great deformations, it clearly follows that in a quiescent state the base-leveling of the land means contemporaneous filling of the sea basins by transferred matter, and hence a slowly advancing sea-edge which is thus brought into active function as a base-leveling agent. This water movement is essentially contemporaneous the world over, and is thus a basis for correlation. *The base-leveling process implies a homologous series of deposits the world over.* At first these represent the conditions immediately following continental rejuvenation. Later they are succeeded by the deposits representing the modified conditions to which the first stage gives rise, and so on through the series up to the climacteric ones when base-leveling has reached its greatest development. After this a declining series follows. The deposits of the more advanced stages of base-leveling are, as now well recognized by most American geologists, markedly different in physical constitution and physiographic aspect from those of the earliest stages of continental rejuvenation. The criteria for discrimination between these earlier and the later members of the series are indeed of the collective rather than the individual type; they have character as distinctive assemblages of criteria rather than as single or isolated criteria, but they are perhaps all the safer for this composite character.

Correlation by base-levels is one of the triumphs of American geology; correlation by its complement, transgressive deposits on a base-level, may easily be added, and perhaps on quite as firm or even firmer physical grounds. If we add the biological element the case is immeasurably strengthened, for correlation by cosmopolitan faunas, the very best of faunas for the purpose, is added to the physical correlation. Migration at the climax of base-leveling and sea-transgression is freer and more prompt than at other times. Correlation to the foot, as by an unconformity, may not be practicable, but the precision of correlation by unconformities has more apparent than real value, for the different parts of the same unconformity vary much in time. All distant correlations involve some measure of inexactness, and the more frankly it is made obvious, the less its liability to mislead.

Correlation by general diastrophic movements takes cognizance of four stages: (1) the stages of climacteric base-leveling and sea-transgression, (2) the stages of retreat which are the first stages of diastrophic movement after the quiescent period, (3) the stages of climacteric diastrophism and of greatest sea-retreat, and (4) the stages of early quiescence, progressive degradation, and sea-advance.

(1) The characteristics of the climacteric stage of base-leveling and sea-transgression need little further characterization here, for the function of base-levels is known to all American geologists and the function of great sea-transgression to every stratigrapher and paleontologist. We have in base-leveling conjoined with sea-transgression, just that combination of agencies which is competent to develop the broad epicontinental seas of nearly uniform depth requisite for an expansional evolution of shallow-water life. At the same time, it furnishes broad pathways around and across the continental surfaces for wide migrations and the comminglings that lead to cosmopolitan faunas of the shallow-water type.

(2) The stages of initial diastrophism and sea-retreat find their criteria in the deposits that spring from an increased erosion of the deep soil-mantles accumulated in the base-level period, in the effects of increasing turbidity, in the lessening areas suitable for the shallow-water life, and in the limitation of migration.

(3) The climacteric stages of diastrophism are marked by the stress of restrictional evolution among the shallow-water species; by increased clastic deposition in land basins, on low slopes, and on sea

borders, by great land extension, but often, perhaps dominantly, by diversity of land surface and by liability to climatic severities and diversification. Areally, land life is favored, but it is hampered by the climatic and topographic diversities, and these may prove graver obstacles to migration and intermingling than even the tongues of sea that previously traversed the land surface. Correlation by glaciation in these stages is likely to prove a valuable adjunct, but we must first test our criterion, for we are not as yet quite sure that contemporaneity of glaciation is inferred on reliable grounds. The shallow-water life of the diastrophic stages is driven into narrow border tracts and into local embayments, and is thus forced into special adaptations and into narrowly provincial aspects.

(4) The early stages of quiescence and of base-leveling, with advancing seas, are peculiarly fruitful in biological criteria, for they are marked by re-expansions of the narrowly provincial shallow-water faunas of the previous stages. The progressive development of these provincial faunas and their successive unions with the faunas of neighboring provinces, as these come to coalesce by means of the progressive sea-advances, form one of the most fascinating chapters in life evolution, and give some of the most delicate of criteria for correlation.

This rough outline is quite too meager duly to set forth the criteria of correlation connected with the stages of general diastrophism. It rather suggests them than sets them forth.

It remains to consider the precedence among themselves of the three factors, diastrophism, deposition, and life development.

We are accustomed to look to the life record as our chief means of correlation. Its very high utility is quite beyond discussion. Thoughtful students, however, recognize that the paleontological record is based, in an essential way, on stratigraphy and that it is corrected and authenticated by the precise place the life is found to occupy in the stratigraphical succession. Stratigraphy and paleontology thus go hand in hand, each sanctioning the other. *Diastrophism lies back of both and furnishes the conditions on which they depend.* The relationship is not reciprocal in any radical sense. The life does not, in any appreciable way, affect diastrophism. Deposition has been thought to be related to mountain-folding.

Erosion in one area and deposition in another has been assigned as an initial agency in deformation. While some influence of this kind may be conceded, I think it is rather a localizing influence than a fundamental one. If wrinkling must take place from other causes, quite possibly previous erosion here and deposition yonder may localize the wrinkling. But that is quite apart from fundamentally causing the wrinkling. Reasons are growing yearly in cogency why we should regard the earth as essentially a solid spheroid and not a liquid globe with a thin sensitive crust. I think we must soon come to see that the great deformations are deep-seated body adjustments, actuated by energies, and involving masses, compared to which the elements of denudation and deposition are essentially trivial. Denudation and deposition seem to me clearly incompetent to perpetuate their own cycles. It seems clear that diastrophism is fundamental to deposition, and is a condition prerequisite to epicontinental and circum-continental stratigraphy.

Diastrophism thus seems to me fundamental both to stratigraphic development and life development. Diastrophic action seems to be the forerunner of both these standard means of correlation. It therefore seems to be the ultimate basis of correlation. The criteria of this correlation include at once its own specific criteria, the criteria of stratigraphy as dependent on diastrophism, and the criteria of paleontology as modified by the direct and indirect effects of diastrophism.